Chapter 2

The emergence of the spatial sciences as a new and integrative field

This chapter traces the intellectual origins and current focus of work in the spatial sciences today; the varying contributions made by theory, practice, and technology; and the flourishing academic, government, business, and not-for-profit communities that have sprung up around the spatial sciences during the past 20 years.

This is a challenging task considering that more than 50 years have passed since Roger Tomlinson and colleagues launched the Canada Geographic Information System (CGIS). Students today can earn degrees in the spatial sciences (or some variant, such as geodesign, geographic information science, spatial data science, spatial informatics, or spatial information science), and the accompanying geospatial technologies contribute billions of dollars of value through their support of a large and varied set of applications that span the public, private, and not-for-profit sectors. Table 2.1 lists the 59 special-interest groups represented at the 2023 Esri User Conference, and a series of reports published during the past 12 years has used a variety of methods and data to quantify the economic value of the geospatial sector (Boston Consulting Group 2012; Oxera 2013; National Geospatial Advisory Committee 2016; AlphaBeta 2016; Open Data Institute 2018; World Geospatial Industry Council 2019; Walter 2020; Geospatial World 2022a, 2022b, 2023a, 2023b; Geospatial Commission 2023).

2.1. The formation and elaboration of the spatial sciences

The intellectual underpinnings and focus of the spatial sciences today rely on two complementary threads. The first focuses on the representation, measurement, and manipulation of geospatial information and the second on the significance and meaning of place for the functioning of Earth and human well-being.

The first thread took shape quickly following the establishment of the National Center for Geographic Information and Analysis (NCGIA) in 1988 after receiving a $5 million grant from the National Science Foundation. The center, hosted by the University of California, Santa Barbara, the State University of New York at Buffalo, and the University of Maine, made important and enduring contributions to education and research. The education contributions included the development of the NCGIA Core Curriculum in GIS, a 1,000-page document with three volumes titled "Introduction to GIS," "Technical Issues in GIS," and "Application Issues in GIS" (Kemp and Goodchild 1991, 1992). The research contributions

Table 2.1. Special-interest groups represented at the 2023 Esri User Conference

Architecture, Engineering, and Construction	Renewable Energy	North Star and Blacks in GIS: People of Black/African Descent in GIS
Construction Management	Small and Medium-Sized Electric Utilities	Statistics and GIS
Design and Engineering	**Geospatial Domain**	Women and GIS
Public Works	GIS for Good	**Resources and Environment**
Built Environment	National Geospatial Authorities	Agriculture
Campus and School Administration	Spatial Data Infrastructures	Forestry
Digital Twins	**Human Security and Public Safety**	Mining
Indoor GIS	Disaster and Emergency Management	Natural Resources and Environment
Land Records	Emergency Communications	Ocean, Weather, and Climate
Pipeline	Fire, Rescue, and EMS	Water Resources: Analysis and Modeling
Planning and Economic Development	Humanitarian	Wildlife
Telecommunications	Law Enforcement	**Sustainability and Conservation**
Business	Security Operations	Conservation
Advanced Spatial Analytics for Customer Intelligence	**People, Health, and Human Services**	Global Sustainable Goals
Corporate Responsibility	Community Engagement	**Transportation**
Insurance	Elections	Airports
Logistics, Freight, and Distribution	GIS for Racial Equity and Social Justice	Ports
Supplier Network Digitization and Analysis	Health and Human Services	Rail
Territory Optimization	**Professional Development and Networking**	Roads and Highways
Energy	ArcGIS® Insights	Transit
Electric Distribution	Cartography	**Water**
Electric Transmission	Drones and Reality Mapping in GIS	Flood Hazards
Gas Utility	Imagery and Remote Sensing	Water Utilities: Lead Service Lines
PUG / Energy Resource	Mobile Workforce	

focused on 19 research initiatives, which started and ended with specialist meetings where interdisciplinary teams discussed pressing research issues. The list of titles reproduced in table 2.2 shows how most of this research focused on the representation, measurement, and manipulation of geospatial information and, to a lesser extent, the social and legal implications of these activities. This list also prefaces the distinction between the spatial information tradition, which stressed large inventories and databases and led to today's geoportals (Samet 1989; Roumelis et al. 2017), and the spatial analysis tradition, which focused on knowledge discovery using rapidly evolving suites of analysis and modeling methods. L. Anselin (1988, 1994), A. Getis and J. K. Ord (1992), Ord and Getis (1996), and C. Brunsdon, A. S. Fotheringham, and M. Charlton (1998) describe examples of spatial analytics that were proposed during this period and that are still in use today.

Michael Goodchild (1992) synthesized these two traditions in an article that reviewed the topics worth including in a science of geographic information (known as GIScience). He identified eight topics—(1) data collection and measurement; (2) data capture; (3) spatial statistics; (4) data modeling and theories of spatial data; (5) data structures, algorithms, and processes; (6) display; (7) analytic tools; and (8) institutional, management, and ethical issues—and argued that research on these fundamental issues is a better prospect for long-term survival and acceptance in the academy than the development of technical capabilities. Twenty years later, H. Couclelis (2012) summarized Goodchild's role in the developments that defined this period in a series of sections titled "Naming," "Adapting," "Accepting," "Persevering," "Educating," and "Leading," and provided evidence that, like any other science, geographic information science, or GIScience, is a social as well as an intellectual enterprise. We perhaps should think of spatial data science, as described in chapter 5, in a similar way.

Many of the topics that Goodchild noted in his 1992 landmark article later appeared in "Geographic Information Science & Technology (GIST) Body of Knowledge" authored by D. DiBiase et al. (2006). This groundbreaking monograph used three tiers to describe the field. The first tier divides GIST into 10 knowledge areas. The second divides each knowledge area into several constituent units made up of coherent sets of topics that embody representative concepts, methodologies, techniques, and applications. The third and final tier comprises 326 topics, spread across the 10 knowledge areas and 73 units. The 10 knowledge areas—(1) analytic methods; (2) conceptual foundations; (3) cartography and visualization; (4) design aspects; (5) data modeling; (6) data manipulation; (7) geocomputation; (8) geospatial data; (9) GIST and society; and (10) organizational and institutional aspects—mimicks the priorities identified by the NCGIA nearly 20 years earlier.

Table 2.2. The 19 research initiatives sponsored by the NCGIA, from 1988 to 1997

Accuracy of Spatial Databases (1988–90)	Integration of Remote Sensing and GIS (1990–93)
Languages of Spatial Relations (1989–91)	User Interfaces for GIS (1991–93)
Multiple Representations (1989–91)	GIS and Spatial Analysis (1992–94)
Use and Value of Geographic Information (1989–92)	Multiple Roles of GIS in US Global Change Research (1994–present)
Large Spatial Databases (1989–92)	Law, Information Policy, and Spatial Databases (1994–present)
Spatial Decision Support Systems (1990–92)	Collaborative Spatial Decision-Making (1994–present)
Visualization of Spatial Data Quality (1991–93)	Social Implications of How People, Space, and Environment Are Represented in GIS (1995–present)
Formalizing Cartographic Knowledge (1993–present)	Interoperating GISs (1996–present)
Institutions Sharing Geographic Information (1992–present)	Formal Models of the Commonsense Geographic World (1996–present)
Spatiotemporal Reasoning in GIS (1993–present)	

This longstanding thread, which focuses our attention on the need to represent, measure, and manipulate information on space and time in precise and reproducible ways, remains important to this day. Hence, Jack Dangermond and Michael Goodchild (2020) recently outlined a further iteration of this thread that reflects today's focus on spatial computing coupled with open and multimodal access, sharing, engagement, the web, big data, artificial intelligence, and data science, and Goodchild (2024), in the foreword he wrote for the *Handbook of Geospatial Artificial Intelligence* (Gao et al. 2024a), describes how GeoAI provides new methods that herald a fundamental shift in the geographic sciences, one that elevates description and prediction over full explanation.

These perspectives serve as a preview for much of what follows in this and subsequent chapters and support Goodchild's (2024) observation that the most immediate need is to explore ways to incorporate nonstationarity, spatial autocorrelation, spatial heterogeneity, and scaling that shape our knowledge and understanding of the geographic domain in our use of these new methods.

The second thread, however, challenges this view of the world, and the two threads taken as a whole fit nicely within the pluralistic, complex, and multiparadigmatic vision of GIScience envisaged by T. Blaschke and H. Merschdorf (2014). This second thread starts with the spatial "turn" that has swept through the sciences, social sciences, and humanities during the past three or four decades. H. J. Scholten et al. (2009) described the explosive growth of spatial methods and their pervasive spread throughout the sciences, but it is the spatial turn in the social sciences and the humanities that perhaps offers the deeper insights in this instance.

The paradigm shift in the social sciences and the humanities has proceeded from the elemental recognition that all human action literally takes place somewhere to a view in which the spatial dimension of social interaction is of paramount importance for understanding all the classic questions about the human condition. This transformation began in the 1970s and peaked in the 1990s, instigated by such thinkers as Yi-Fu Tuan (1977), David Harvey (1989), Edward W. Soja (1989), Henri Lefebvre (1991), Edward S. Casey (1997), Michel Foucault (1998), and Doreen Massey (2005). The impact has gone furthest in the social sciences, and bookshelves now groan under the weight of recent discussions of place and space. This influence has also spread to the humanities, in which many studies now consider the spatial dimension of their research questions (Ethington 2007).

The spatial humanities are novel because the mode of analysis blends the computational and GIS-based methods noted earlier with the interpretive and qualitative methods of spatial analysis popularized by humanists. The latter includes work on the historically layered urban environment, spaces of representation, and so on, that have no need for GIS or quantification. These methods and ways of understanding our world have applicability far beyond the traditional purview of the humanities, and as such, they provide the second thread that has contributed to the rise of the spatial sciences as a new and vibrant discipline.

D. J. Bodenhamer et al. (2013) describes how the two threads set up a clash between the rigorously precise measurements that characterize the first thread and the uncertainty and ambiguity that pervades life and place in the second thread. The latter relies on a new epistemology, one that is nonlinear, fluid, and reflexive and focuses on the use of space and time to reveal the complex and contingent context of processes and events with and across space and time (similar to Mikhail Bakhtin's [1982] chronotope). His "deep" maps, for example, recognize that people and personal experiences are central to a place's identity. Hence, they anticipate the fact that a single place may be perceived in multiple ways, all of which create different meanings and invite different methods of analysis (Gregory et al. 2019). In this sense, the map is greater than the simple display of geospatial data because it is flexible, user-centric, path traceable, open and immersive, and as such capable of portraying the "situatedness" of the storyteller (Bodenhamer et al. 2013, 2015).

This second thread, therefore, has enormous potential for understanding nearly every aspect of the human condition, including the connections between history, health, and place. Susan Kemp, for example, has written that "setting place outside of history flattens human experience, reducing it to a single plane of the present, and obscuring the deep-rooted social, political, and economic mechanisms at the core of health disparities" (Kemp 2010, 16). This view also means that place histories and collective memories are particularly important to the identity and well-being of minority groups, including Indigenous people. In addition, historical patterns of social and environmental risk may significantly influence human health and well-being and mean that inequalities in health (and life generally) are often a historical phenomenon (Namin et al. 2020).

These same approaches and ideas around the meaning of place may also inform our understanding of biological pathways in health-related applications. A. K. Conching and Z. Thayer (2019), for example, have proposed a conceptual model with two pathways by which historical trauma might lead to epigenetic modifications. The first pathway captures the role of individual experience and the second the intergenerational effects. Similarly, J. Pearce (2015) has described how in utero exposures, childhood poverty, and changes in urban green space and air pollution might influence physical and mental well-being. M. Vrijheid (2014) has cast these same ideas as the accumulation of social, economic, and environmental exposures over the life course in the exposome (figure 2.1).

It is also the case that care is required when using spatial methods to characterize these kinds of relationships because geospatial information presents several unique problems,

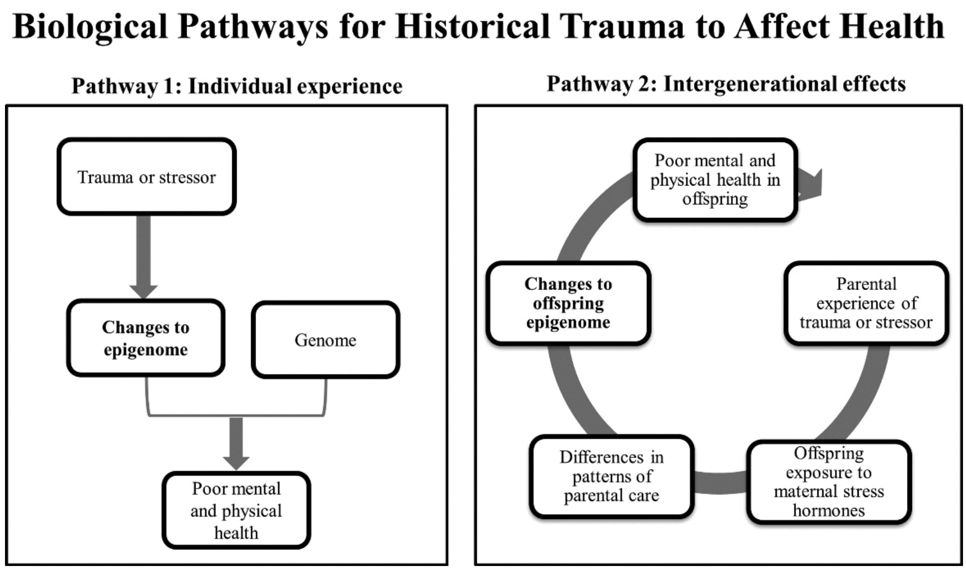

Figure 2.1. The exposome concept. From M. Vrijheid (2014, 877).

such as scaling, spatial autocorrelation, spatial heterogeneity, and nonstationarity (Getis 2008; Milly et al. 2008; Goodchild 2009; Robertson and Feick 2018). Some new methods have been developed that can address these problems and find valuable insights in spatial information, as illustrated by S. D. Nyadanu et al. (2019), who provide a geovisual integration of health outcomes and risk using excess risk and conditioned choropleth maps for a case study of malaria incidence and sociodemographic determinants in Ghana. In addition, many spatial approaches endeavor to transform these so-called problems (that is, spatiotemporal properties) into assets when building statistically strong spatial models and predictions. These include kriging (Oliver 1990), thin plate splines (Hutchinson 1995), new indicators of spatial association (Anselin 2019b), spatial econometrics (Anselin 1989; Anselin and Rey 2014), geographically weighted regression (GWR) (Fotheringham et al. 2002), and spatial regression using eigenvector spatial filtering (Griffith et al. 2019), among others.

The delineation of the pathways in Conching and Thayer (2019), Pearce (2015), and Nyadanu et al. (2019) requires both of the aforementioned threads that characterize the spatial sciences today. The representation, measurement, and manipulation of spatiotemporal information using complicated computational methods (thread 1) and the nonlinear, fluid, and reflexive methods required to understand specific places (thread 2) complement one another and play a key role in our efforts to tackle nearly all the wicked problems that confront society today (Scott and Rajabifard, 2017).

These problems include climate change, freshwater shortages, and species extinctions, among others, and the increasing inequities and inequalities that characterize the human condition and threaten human security and well-being across the world. The 67 geospatial applications featured in Esri's *ArcUser* magazine from 2021 and 2023 (table 2.3), for example, span 11 application domains—disaster management, economic development, environmental management, health applications, humanitarian operations, infrastructure management, land administration, real estate and historic preservation and housing, social equity, urban development and planning, and water management—that match or overlap with many of the focus areas of the special-interest groups listed in table 2.1.

Table 2.3. Geospatial domains and applications featured in *ArcUser*, from 2021 to 2023

Domains	Applications
Disaster management	Baker, T. 2023. "Students Protect the Unhoused from Wildfires." *ArcUser* 26 (1): 62–64.
	Baumann, J. 2022. "Understand and Mitigate Risks on a Global Scale." *ArcUser* 25 (2): 16–17.
	Bialousz, M. 2022. "Plant Back Better: Mapping Recovery Plans for a Climate-Resilient Forest." *ArcUser* 25 (1): 14–17.
	Cottry, O. 2023. "Drone Mapping and AI Combine to Find Flood Victims Faster in Mozambique." *ArcUser* 26 (1): 66–70.
	Lanclos, R. 2021. "Students Used GIS to Respond to the Great Flood of 2019." *ArcUser* 24 (3): 58–61.
	Speranza, C. 2023. "Interactive Maps Tell the Story of Modern Risk Mitigation in Florida." *ArcUser* 26 (3): 16–19.
	Suresh, A., and V. Viswambharan. 2022. "ML Aids Geospatial Assessment for Disaster Response." *ArcUser* 25 (2): 28–29.
	Wright, D. 2023. "Climate Action: Reasons for Hope." *ArcUser* 26 (1): 32–36.
Economic development	Cooke, K. 2023. "GIS Maps a Path to Economic Mobility." *ArcUser* 26 (3): 36–39.
	Bills, T. 2022. "Identifying the Solar Potential Next to America's Highways." *ArcUser* 25 (2): 18–20.
	Walter, C. 2022. "Cobb County Secures World Series in Real Time." *ArcUser* 25 (2): 66–70.
Environmental management	Anon. 2021. "AI Enables Rapid Creation of Global Land Cover Map." *ArcUser* 24 (3): 12-13.
	Anon. 2022. "3D Mapping Helps EPA Preserve Freshwater Resources." *ArcUser* 25 (4): 18–19.
	Anon. 2023. "Using GIS to Control a Big Snake Problem in the Everglades." *ArcUser* 26 (3): 66–70.
	Davies, R. 2021. "Helping Safeguard Threatened Raptors Worldwide." *ArcUser* 24 (1): 66–70.
	Dilts, T., J. Van Gunst, and J. C. Vardaro. 2021. "Mapping Pikas' Habitat to Help Save Them." *ArcUser* 24 (3): 24–25.
	Duggan, N. 2021. "Digitally Transforming Field Data Capture to Save Sea Turtles." *ArcUser* 24 (2): 66–70.
	Gadsden, D. 2023. "A Nature-Based Solution to Human-Elephant Conflict." *ArcUser* 26 (2): 66–70.
	Jones, M. 2022. "Mapping the Geography of Underground Ecosystems." *ArcUser* 25 (2): 22-25.
	Pratt, M. 2021. "To Better Understand the Earth." *ArcUser* 24 (3): 14–18.
	Pratt, M. 2023. "Supporting the Science that Saves the Ocean." *ArcUser* 26 (2): 40–47.
	Rice, J., J. Whitacre, and B. Stouffer. 2022. "Optimizing Bird Migration Tracking with ArcGIS." *ArcUser* 25 (4): 10–13.
Health applications	Gross, J., and D. Phelan-Emrick. 2023. "Matching COVID-19 Cases to Facilities: Lessons Learned." *ArcUser* 26 (3): 8–11.
	Geraghty, E. 2023. "Harnessing Geospatial Data for Informed Health-Care Planning." *ArcUser* 26 (3): 12–13.
	Galindo, C. 2021. "Using GIS to Effect Change for the ALS Community." *ArcUser* 24 (4): 58-61.
	Pratt, M. 2022. "Supporting Midwives Worldwide." *ArcUser* 25 (3): 66–70.
	Smyth, J., and P. O'Brien. 2023. "Revealing Opioid Diversion with ArcGIS AllSource™." *ArcUser* 26 (3): 14–15.

Table 2.3. *continued*

Humanitarian operations	Baumann, J. 2022. "Geospatial Analysis Targets Aid in Sudan." *ArcUser* 25 (4): 66–70.
	Lehman, R. 2021. "A Growing Hunger." *ArcUser* 24 (1): 22–23.
	Lindemann, J. 2022. "ArcGIS Solutions Helps Communities Assist People Experiencing Homelessness." *ArcUser* 25 (1): 36–37.
	Milner, G. 2022. "Offering Hope to Those Left Behind in Afghanistan." *ArcUser* 25 (1): 66–70.
	Merani, P. B. T. 2021. "US Border Patrol Uses ArcGIS to Rescue Migrants." *ArcUser* 24 (4): 10–13.
Infrastructure management	Anon. 2021. "ArcGIS GeoBIM connects projects in context." *ArcUser* 24 (4): 8–9.
	Anon. 2022. "Better Wayfinding on Campus with Indoor Mapping." *ArcUser* 25 (2): 62–64.
	Baumann, J. 2021. "Interactive Map Depicts Global Submarine Cable Networks." *ArcUser* 24 (1): 30–31.
	Bills, T., and I. Koeppel. 2023. "A Digital Twin Guides Underground Rail Expansion." *ArcUser* 26 (2): 10–14.
	Boden, S. 2022. "Small Team Makes a Big Impact with Enterprise GIS." *ArcUser* 25 (1): 22–25.
	Davis, C. 2022. "Dashboard Makes Street Rating Data More Valuable." *ArcUser* 25 (3): 20–22.
	Doroba, J. 2022. "Site Suitability Modeling for Locating Tidal Buoys." *ArcUser* 25 (1): 18–21.
	Hills, K., C. Smith, and M. Aquino. 2023. "Decades of Innovation by Orange County." *ArcUser* 26 (3): 24–25.
	Hussain, K. 2022. "Hydrocarbon Transmission Pipelines Managed with GIS Dashboard." *ArcUser* 25 (3): 12–15.
	Min-Chen, W. 2021. "Fighting Snow More Effectively with GIS." *ArcUser* 24 (4): 18–21.
	Shinnick, D. 2023. "App Saves Time and Adds Flexibility and Transparency to Capital Funds Spending." *ArcUser* 26 (3): 20–23.
	Sterbentz, N. 2022. "Highway Data Collection Improves Operations and Saves Money." *ArcUser* 24 (4): 14–17.
Land administration	Aldrich, E. 2021. "Conserving a Network of Climate-Resilient Lands." *ArcUser* 24 (1): 26–29.
	Anon. 2021. "Machine Learning Becomes Part of the Fabric of Kuwait." *ArcUser* 24 (2): 12–15.
	Anon. 2023. "Using GIS to Promote Appraisal Transparency and Efficiency." *ArcUser* 26 (2): 20–21.
	Baumann, J. 2022. "Oman's Unified Addressing System Will Have Broad Benefits." *ArcUser* 25 (3): 16–18.
	Cooke, K. 2022. "Data-Driven Zoning Reform." *ArcUser* 25 (4): 24–25.
	Frye, C. 2022. "A First Glimpse into the Future of Population Data." *ArcUser* 25 (2): 8–10.
Real estate and historic preservation and housing	Anon. 2023. "New Map Style Helps See the Future of Housing in Utah." *ArcUser* 26 (2): 16–17.
	Anon. 2023. "GIS Aids Housing Equity." *ArcUser* 26 (2): 18–19.
	Cooke, K. 2021. "Taking a Data-Driven Approach to Affordable Housing." *ArcUser*, 24 (1): 24–25.
	Cooke, K. 2021. "Leveraging Site Suitability Analysis to Validate Policy." *ArcUser* 24 (2): 28–29.
	Cooke, K. 2023. "Using GIS to Map the Way to Housing Equity." *ArcUser* 26 (2): 26–27.
	Cooke, K. 2023. "How GIS Mitigates the Impact of Vacant Office Space." *ArcUser* 26 (3): 26–27.
	Ingram, U., and G. Shirley. 2022. "Finding the Most Suitable Sites for US embassies." *ArcUser* 25 (3): 64–65.
	Patrick, B. 2022. "Using a Digital Twin to Envision a Future that Honors the Past." *ArcUser* 25 (4): 36–43.
	Rich, S. 2022. "Mapping Past Contamination Helps Cities Plan for Renewal." *ArcUser* 25 (3): 24–27.
Social equity	Bordne, M., and C. Johnson. 2021. "Using Geography to Apply an Equity Lens to Projects and Policies." *ArcUser* 24 (2): 56–58.
	Brown, M. 2022. "Social Equity Analysis Solution Supports Better Policy Decisions." *ArcUser* 25 (1): 34–35.
	Cummens, P. 2021. "Online Schooling Prompts Municipalities to Map Digital Inequities." *ArcUser* 24 (1): 18–21.
	Meriam, E., R. Donihue, and C. McCabe. 2021. "The Legacy of Redlining Continues to Color Cities." *ArcUser* 24 (2): 50–54.
	Van Deusen, J. 2021. "If More Women Owned Land, More People Might Be Fed." *ArcUser* 24 (4): 66–70.

Table 2.3. *continued*

Urban development and planning	Cooke, K. 2022. "A Geographic Approach to Planning." *ArcUser* 25 (2): 30–31.
	Cooke, K. 2023. "Understanding Current Assets and Future Needs with Digital Twins." *ArcUser*, 26 (1): 16–20.
	Goldsmith, S. 2021. "Regional Data Platform Strengthens Collaboration and Cooperation." *ArcUser* 24 (1): 42–45.
	Milner, G. 2021. "South Korean City Uses a Digital Twin to Meet Challenges." *ArcUser* 24 (3): 20–23.
Water management	Anon. 2022. "Seeing Data in Context Enables Better Decisions." *ArcUser* 25 (4): 14–16.
	Campbell, C. 2022. "Students' Solution Protects People from Contaminated Water." *ArcUser* 25 (2): 58–61.
	Campbell, C. 2023. "Improved Location Accuracy Enables Hydraulic Modeling." *ArcUser* 26 (1): 8–11.
	Campbell, C. 2023. "Geoenabling the Modern Water Utility." *ArcUser* 26 (1): 12–13.
	Campbell, C., and S. Garcia. 2023. "More Green, Less Gray: LA County Maps Big Plans for Its Water Supply." *ArcUser* 26 (4): 14–17.
	Campbell, C. 2023. "Building a Service Line Inventory." *ArcUser* 26 (3): 26–29.
	Fleming, S. 2023. "Combating Forever Chemicals." *ArcUser* 26 (3): 18–20.
	Patarasuk, R. 2023. "Saving Water by Tracking Code Violations." *ArcUser* 26 (3): 22–24.
	Wheeler, C. 2021. "Saving Water, Money, and Time with GIS." *ArcUser* 24 (3): 66–70.

2.2. The fusion of theory, practice, and technology

It is perhaps also not surprising considering the ways in which the intellectual focus was cast in the prior section that the spatial sciences now support large and diverse practice and technology components as well. These provide opportunities for both fundamental and applied research and teaching and support many diverse career tracks for spatial science graduates. The three elements—theory, practice, and technology—can reinforce and complement one another as long as spatial scientists and practitioners can move fluidly between the three concepts highlighted in figure 2.2.

The spatial sciences practice component has also become much larger and more formalized over time. The first *Geographic Information Science & Technology (GIST) Body of Knowledge* (DiBiase et al. 2006), for example, served as a major milestone that has helped spawn several derivative products during the past two decades. These include the US Department of Labor's Geospatial Technology Competency Model (DiBiase et al. 2010), the GIS Certification Institute's Certified Geographic Information Systems Professional (GISP) Program (GISCI 2023), the US Geospatial Intelligence Foundation's (USGIF) collegiate accreditation program (USGIF 2024), and the University Consortium for Geographic Information Science's GIST Body of Knowledge 2.0 project (Wilson 2024).

There is also a large and growing workforce: the GISCI website, for example, claimed that there were 675,000 geospatial professionals employed in the US in 2021, with 56 percent employed by some level of government and 25 percent having the title GIS analyst. In addition, the number of geospatial professionals who have earned GISP certification exceeds

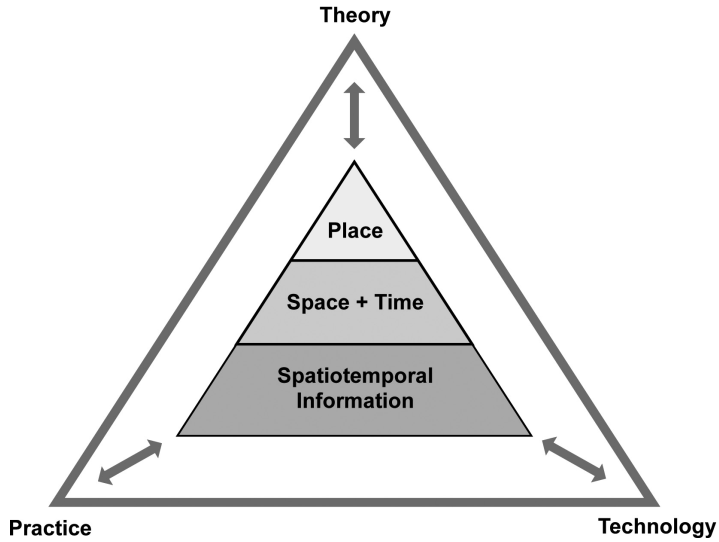

Figure 2.2. The focus on place, space, time, and spatiotemporal information and the complementary roles of theory, practice, and technology in the spatial sciences.

10,800 spread across 59 countries, and there are now 21 colleges and universities with one or more accredited academic programs that match the knowledge and skills identified by USGIF in its Essential Body of Knowledge.

However, the value of these accreditations and certifications is difficult to judge. Mathews and Wikle (2017), for example, surveyed 1,731 geospatial professionals who became certified GISPs between 2003 and 2014 and reported that perceptions about certification span a wide spectrum, with GISPs employed in private industry seeing fewer benefits compared with those employed in government or not-for-profit organizations.

The technology component includes an increasing number and variety of vibrant proprietary and open-source platforms for acquiring, organizing, analyzing, modeling, and visualizing geospatial information.

The leading technology provider is Esri®, whose flagship ArcGIS® suite provides a one-stop system of record, insight, and engagement and supports work with geographic information across many disciplines and application domains around the world (figure 2.3). This suite supports 2D and 3D data collection and management, imagery and remote sensing, spatial analysis, data science, mapping and visualization in 2D and 3D, and field operations using four complementary foundation products—ArcGIS Enterprise, ArcGIS Online, ArcGIS Platform, and ArcGIS Pro—as shown in figure 2.4.